Elliptical Orbits Curriculum Pack

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The ***Astronomy For Educators Workshop*** will be held on December 2nd (Elliptical Orbits), December 9th (Exploring Lunar Phases), and December 16th (Exploring the Lunar Surface).

The workshop focuses on Dr. Barth's ***Low-Cost Science*** methods for teaching astronomy and space science. The intent of Low-Cost methodology is to enable every school, teacher, and student to enjoy a quality astronomy education without significant expense. Dr. Barth believes that a quality STEM education is the right of every child – and that no one should lack a powerful STEM experience because funding for expensive lab equipment is lacking.

Comments, and reviews of these materials may be posted on social media, or emailed directly to Dr. Barth. Questions about the activities may be addressed to Dr. Barth at: AstronomyForEducators@gmail.com

About the Author:

Dr. Daniel E. Barth is Assistant Professor of STEM Education at the University of Arkansas, USA. Dr. Barth has more than 40 years of experience teaching astronomy and physics at secondary and university levels, and training STEM educators in the United States. Dr. Barth has been a Reagan Scholar, Research Corporation Fellow, and Science is for Kids Foundation Fellow. Dr. Barth's work has been recognized by UNESCO, the Amgen Award for Science Teaching Excellence, the Global Campus Award, and more. Published works include:

Science Texts:

Astronomy for Educators

Observational Astronomy

Teaching Science Through Literature

Fiction:

Maurice on the Moon

The Doomed Colony of Mars

Crisis on the Far Side

Revolt in Volkov Crater

Astronomy Activity:

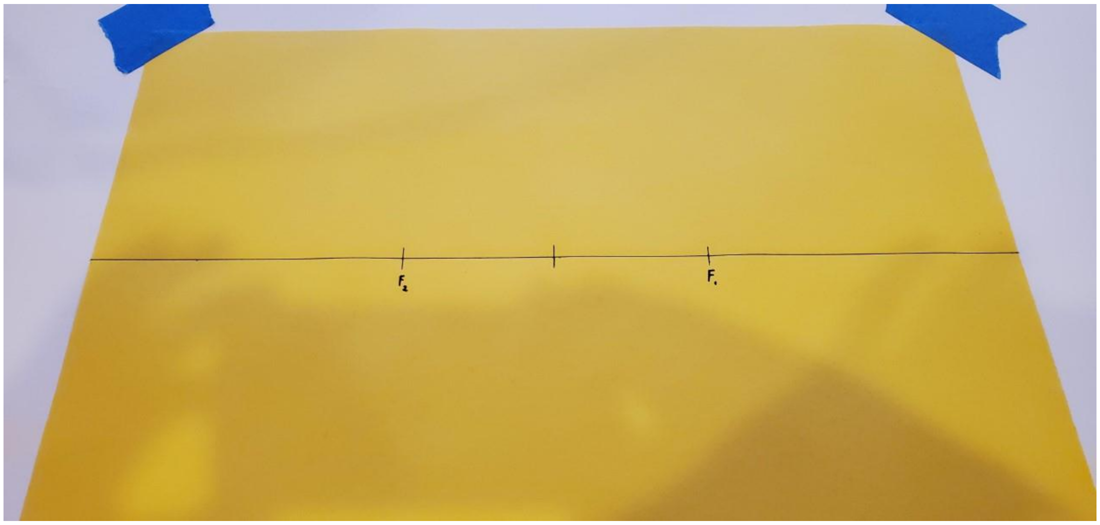
Gravitation and Orbits

Materials:

- One large sheet drawing paper
- 24-30" of string, tied into a loop
- Two pencils (for focus points)
- Ruler and colored pencils

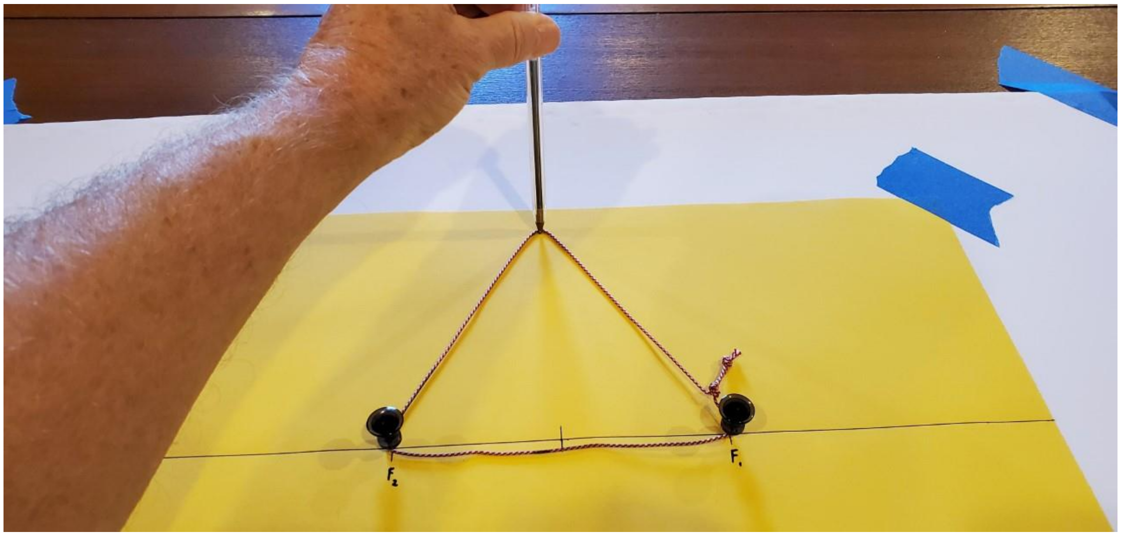
Instructions:

1. Draw a light ***centerline*** down the length of your paper.
2. Mark the center of the paper with a dot.
3. Mark two ***focus points*** on the centerline. They should be 8-20cm apart and equally spaced from the center point. One of these focal points will represent the Earth, but this could easily be any planet or star you choose.

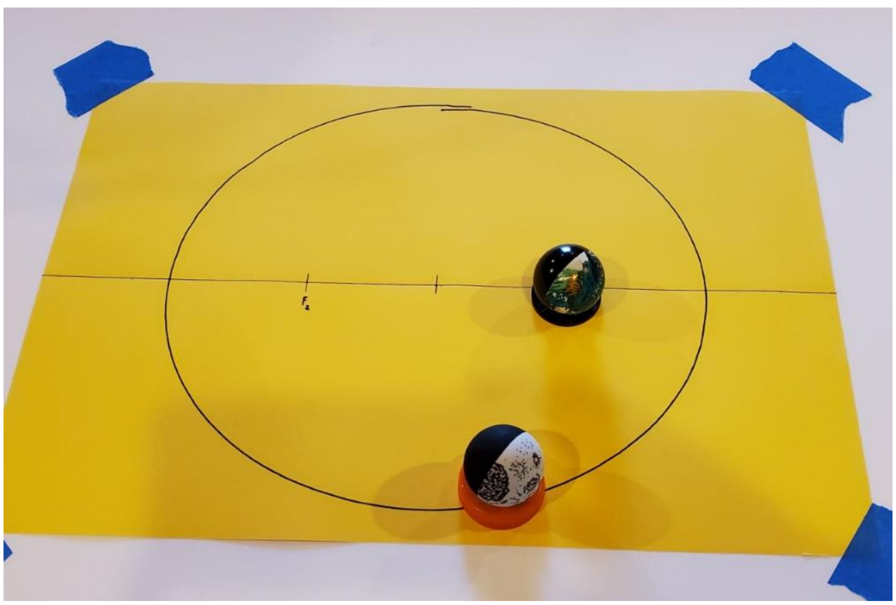


4. Adjust the loop of string so that it will <u>almost</u> reach to the top of the page when wrapped around the focal points.

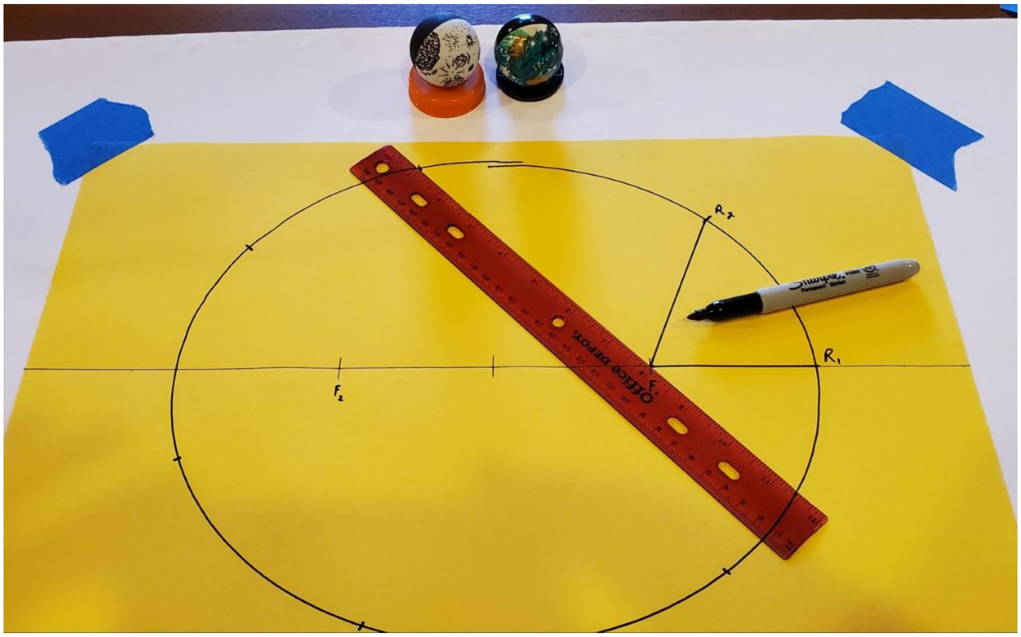
5. Your partner holds a pencil over each focus point. The loop of string guides a pencil to trace the ellipse as shown below. It is recommended that you trace the loop with your finger first, to make sure that the ellipse will fit entirely on the paper! (I've used push pins here – if you have students working remotely, this is what they will do.)



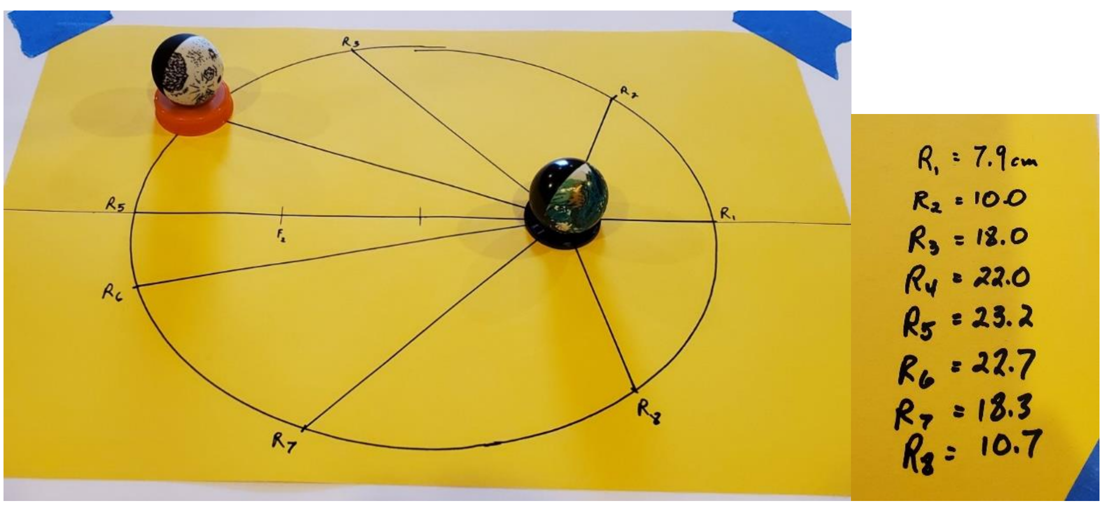
6. Place your Earth and Moon models on the diagram. You may wish to mark the ***Apogee and Perigee points*** (points where the Moon is farthest and nearest to Earth respectively.)



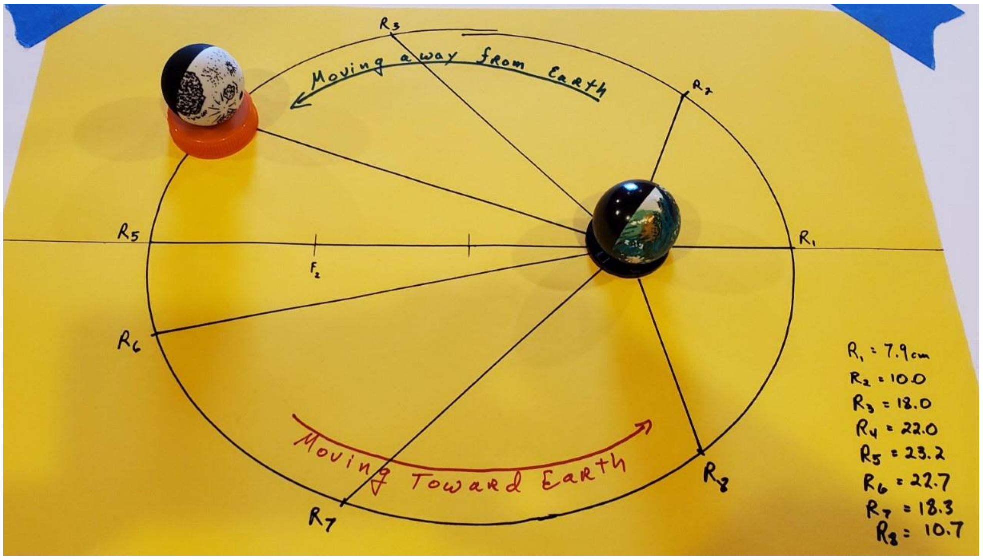
7. Starting with the ***perigee point,*** mark 8 points around the ellipse. These needn't be symmetrical, the activity often works better if they are not. Draw a line from Earth's position (F_1) out to each of the points and mark them R_1 through R_8.



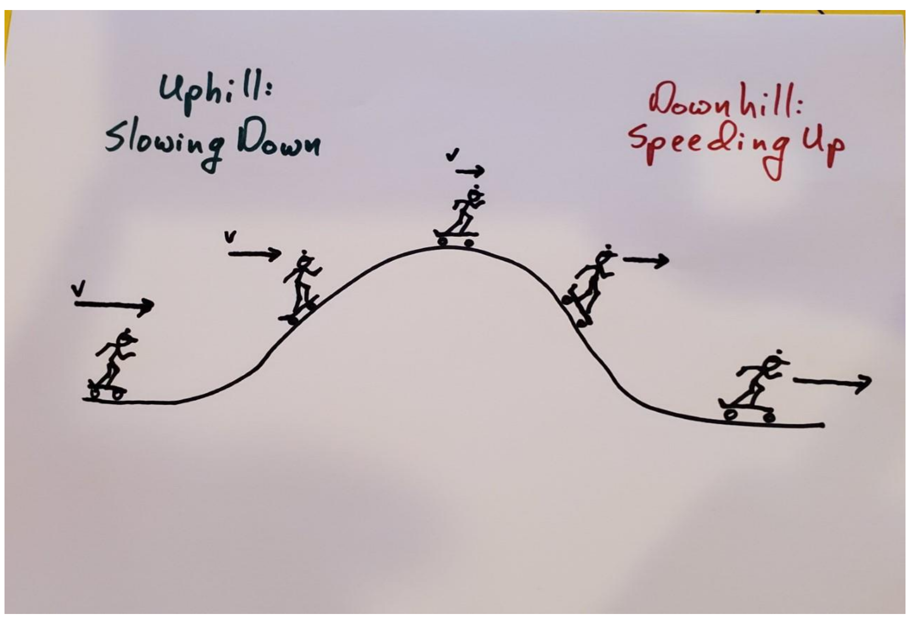
8. The lengths of each line (cm) represents the distance from Earth to Moon at that particular point in orbit. (Note: we are measuring from planetary centers rather than their surfaces!)



9. With the distances measured, we can now divide the Moon's orbit into two halves, one part where the Moon is moving away from the Earth, and the other half where the Moon is moving back toward the Earth. At this point, students may not see the connection to gravity and the way things move on Earth – the next part of the activity will draw that connection!

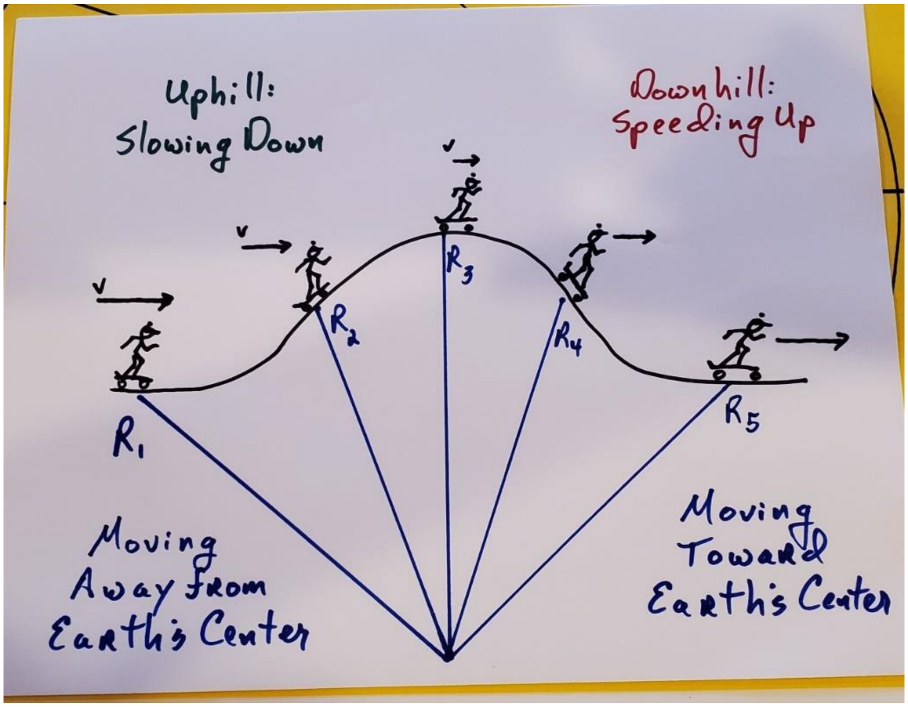


10. This part can be done with a drawing, but I think it is more effective if done with a marble and some vinyl sheeting. (plastic track for toy cars also works well!) Roll the marble up the hill, and then let it roll back down the other side. Challenge your students to describe what happens to the speed of the marble or toy car as it rolls along! Even very young students should be able to see the change in speed easily.

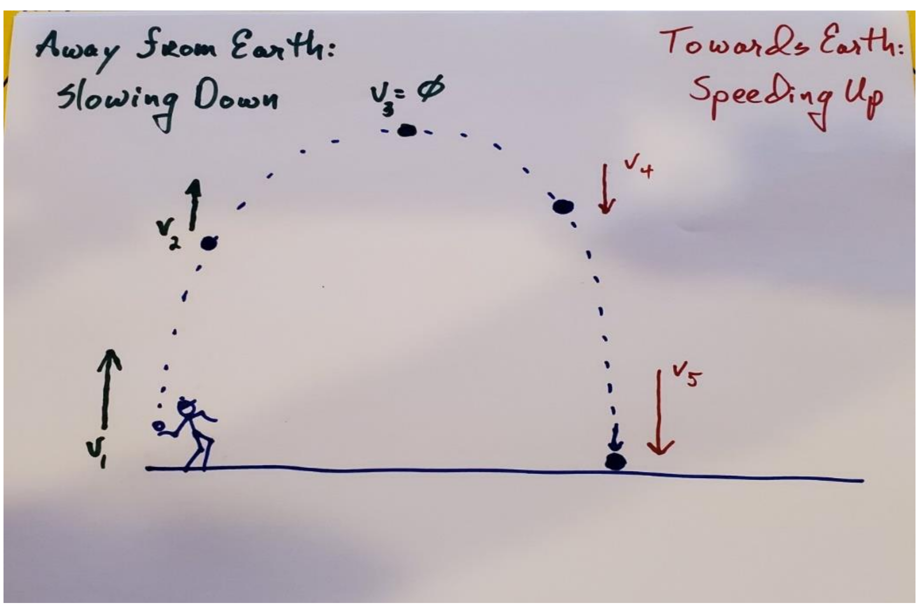


11. The unique connection you can then make is how the change in speed of the marble or toy car ***relates to its distance from the center of the Earth!*** Of course, if you ask, the students will probably say the cause of the speed change is ***gravity!*** Certainly, almost every child will realize that it is gravity that pulls a cyclist down a hill and causes speed to increase. Some students may

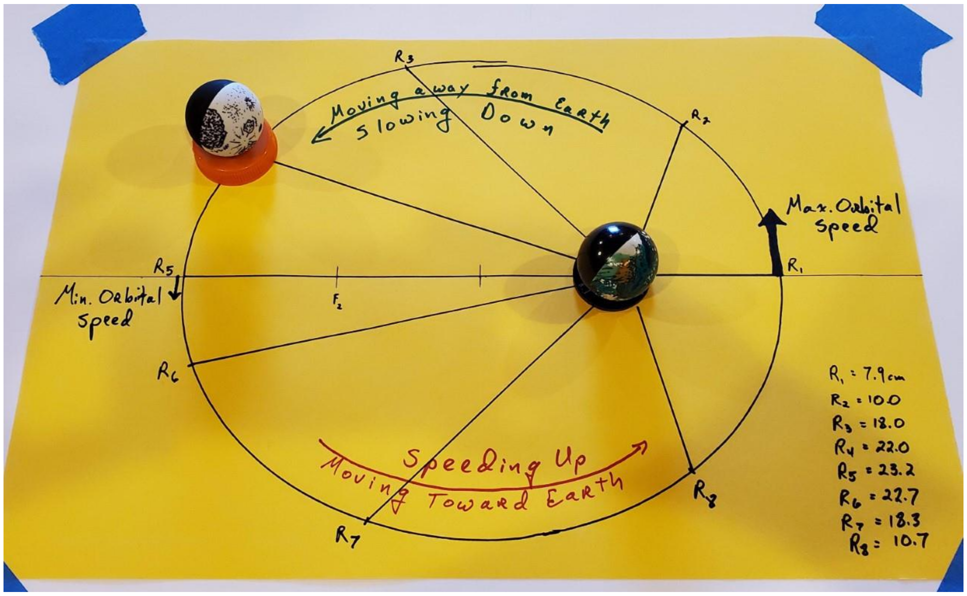
not make the connection that gravity also slows the cyclist down as they go up a hill. It is a common misconception that the ***slope of the hill*** changes the speed rather than gravity.



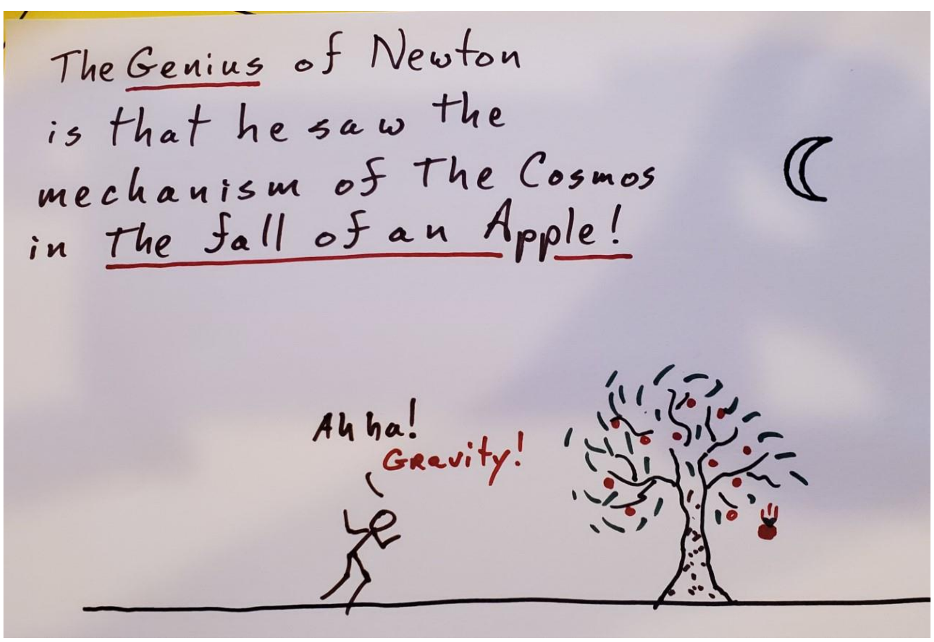
12. Once the students have the idea of gravitation changing the speed of any object rolling up and down a hill, then ask them to analyze the speed of a ball as it is thrown up and allowed to fall down again. By the way, using an object rolling on a slope rather than falling straight down is a trick to borrowed from Galileo! He realized that the slope slows the acceleration down and makes it easier to see!



13. With the idea of gravity acting to change the speed of an object being firmly related to the object's distance from the surface of the Earth, it is time to go back to the diagram we made of the Moon's orbit around the Earth. Students can now clearly see that as the Moon moves away from Earth, it must slow down (gravity acts on everything equally,) and once the Moon passes its apogee point, it must again begin speeding up in orbit. Students can mark maximum and minimum speed points to coincide with the perigee and apogee points respectively.



14. Now we see the real genius of Newton, to see the mechanism of the Cosmos (gravity) by linking the fall of the apple in the orchard to the motion of the Moon around the Earth!



Elliptical Orbital Motion:

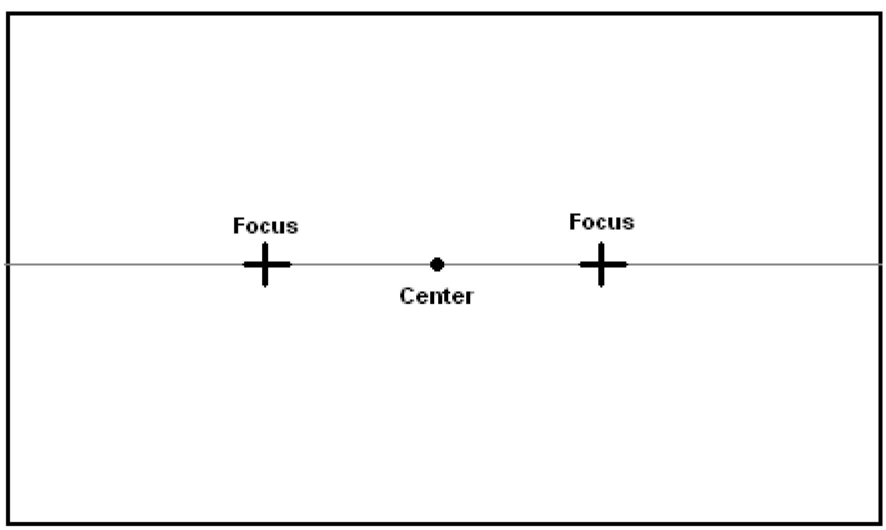
Newton and Kepler Triumphant!

Materials:

- One large sheet drawing paper
- 60cm of string, tied into a loop
- Two pencils (for focus points)
- Ruler and colored pencils

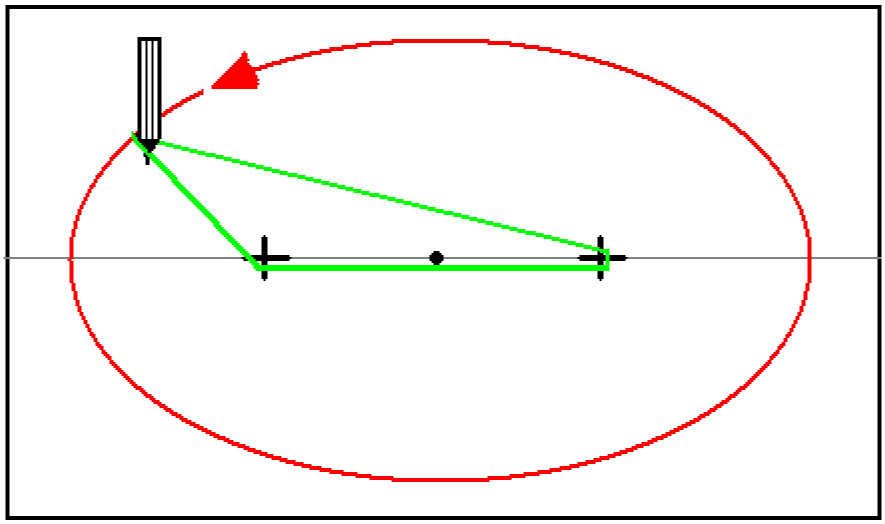
Instructions:

1. Draw a light ***centerline*** down the length of your paper.
2. Mark the center of the paper with a dot.
3. Mark two ***focus points*** on the centerline. They should be 8-20cm apart and equally spaced from the center point. Ideally, the loop will stretch from one focus point to the edge of the paper (running the long way). Check the positions of the focus points by stretching the loop over them and make sure the string does not run off the paper (running the narrow way). If the loop runs off the paper – spread the focal points out a bit until a good fit is obtained. If you don't have a partner, use push pins (or similar) to mark the focus points as you draw the ellipse.



Preparing to Draw an Ellipse

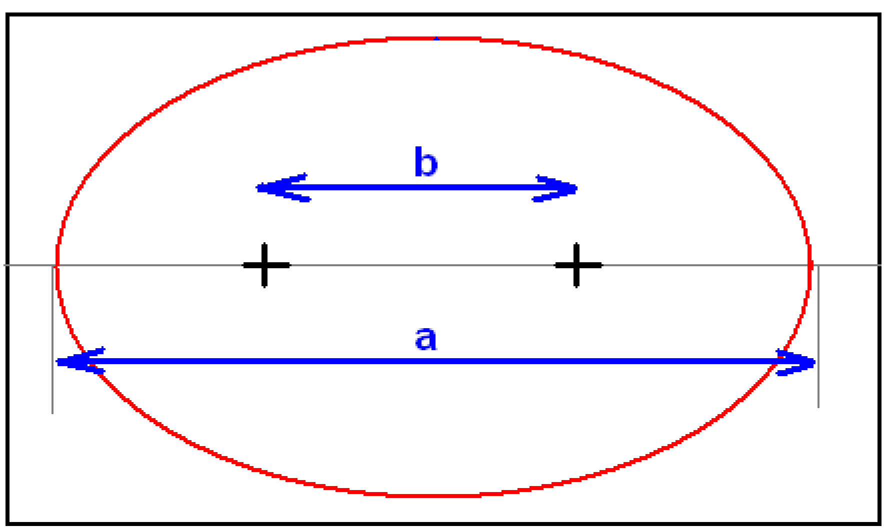
4. Adjust the loop of string so that it will almost reach from the edge of the paper to the farthest focus along the centerline.
5. Your partner holds a pencil over each focus point. The loop of string guides a pencil to trace the ellipse as shown below.



Use String to draw the Ellipse

6. Measure and record the size of the Major & minor Axes and the Inter-focal distance (b). Circumference is best measured by marking off centimeters around the entire distance.

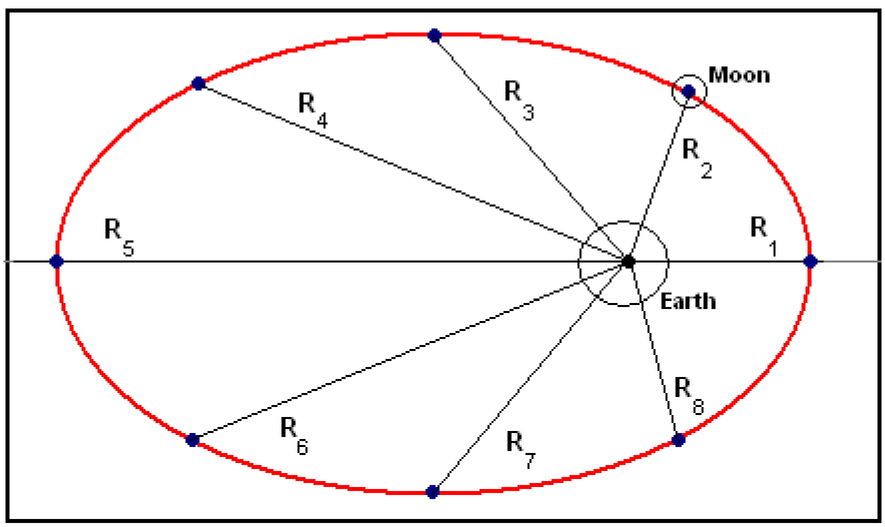
- Major Axis = _________________
- Minor Axis = _________________
- Circumference = _________________
- Inter-focal Dis. = _________________



Calculating Eccentricity and Circumference

7. Draw the Earth at one of the focal points.
    - Mark the closest point to Earth on the orbit as the ***Perigee Point***
    - Mark the farthest point from Earth on the orbit as the ***Apogee Point***
8. Draw ***arrows*** on the orbit indicating the anti-clockwise motion of the Moon in orbit.
9. Measure the circumference, marking off each centimeter with a ruler.
10. Divide the circumference of your ellipse by 27.3 = ____________________
    - What is this measurement? (think about the Moon's orbit)
    - Mark this distance on your orbit, starting at the ***perigee point*** and moving ***clockwise.***

11. Multiply the distance you calculated (in step 9) by 7 and mark this distance on your orbit starting at the ***apogee point*** and moving ***clockwise.***
    - What is this measurement? (think about the Moon's orbit)
12. Mark eight points around your ellipse, starting at the perigee point. Draw a line from one focus to each of these points. Mark them as R_1 to R_8, starting at the perigee point and moving anti-clockwise.
13. Measure and record the physical length of each of these radius lines in centimeters in data table #1



Changing distance between Earth and Moon

14. Set the value of V_{T1} = 100, then calculate V_T = _____ for positions 1-8 in data table #1.
15. Use Fg_1 = 100, then calculate the Fg for each position 1-8 in data table #1.
16. Divide your orbit in half,
    - Show which half of the orbit is "uphill" where the Moon is always slowing down as it travels around the Earth.
    - Show which half of the orbit is "downhill", where the Moon is always speeding up as it travels around the Earth.

Conclusion:

Compare your drawing of orbital speeds and forces with the diagram of Kepler's 2nd law of planetary motion. Discuss how Kepler's 2nd Law is related to Newton's Law of Universal Gravitation.

- Which idea came first historically?
- Are these ideas related? If so, explain how.
- Does one of these ideas prove or confirm the other?
- Which law do you think is more *general* – useful in a greater variety of situations?

Data Table #1	Radius	V_T	F_G
R_1		100	100
R_2			
R_3			
R_4			
R_5			
R_6			
R_7			
R_8			

Force of Gravity

$$F_g = \sqrt{\left(\frac{R_1}{R_2}\right)}$$

Tangential Velocity

$$V_T = \left(\frac{R_1}{R_2}\right)^2$$

Note: This formula calculates the force and speed at point #2. For point #3 use (R_1/R_3), for point #4, use (R_1/R_4), etc. Show your sample calculations below.

Elliptical Orbital Motion:

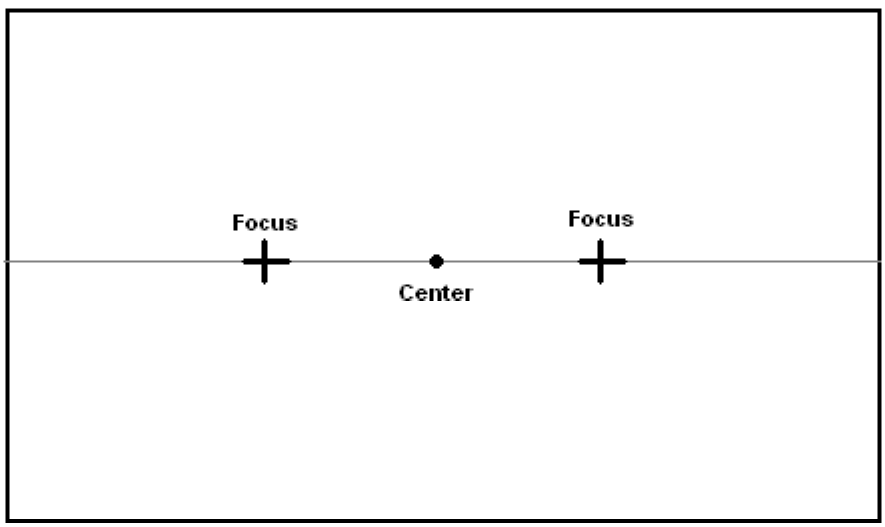
Kepler Laws in Action!

Materials:

- One large sheet drawing paper
- 24-30” of string, tied into a loop
- Two pencils (for focus points)
- Ruler and colored pencils

Instructions:

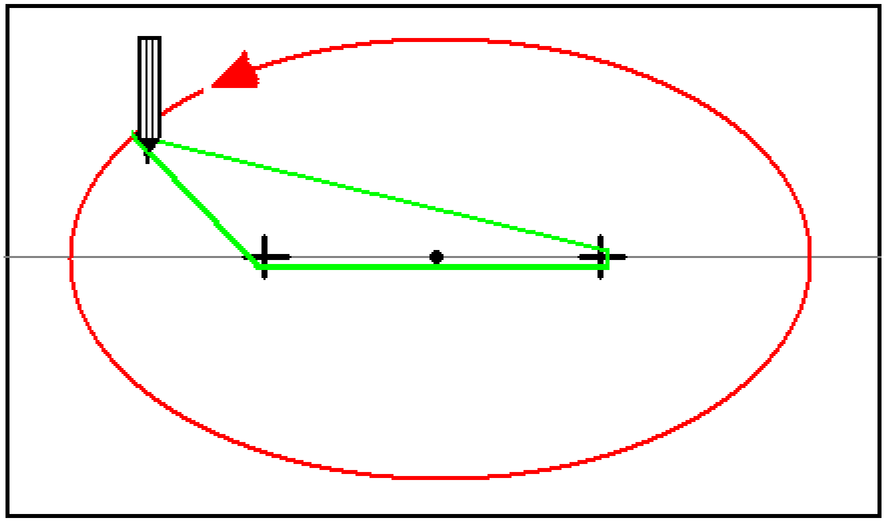
1. Draw a light ***centerline*** down the length of your paper.
2. Mark the center of the paper with a dot.
3. Mark two ***focus points*** on the centerline. They should be 8-20cm apart and equally spaced from the center point. One of these focal points must be labeled as your ***star***. Choose a ***star name*** from your planisphere or a star map and label it!



Preparing to Draw an Ellipse

4. Adjust the loop of string so that it will almost reach from the edge of the paper to the farthest focus along the centerline.

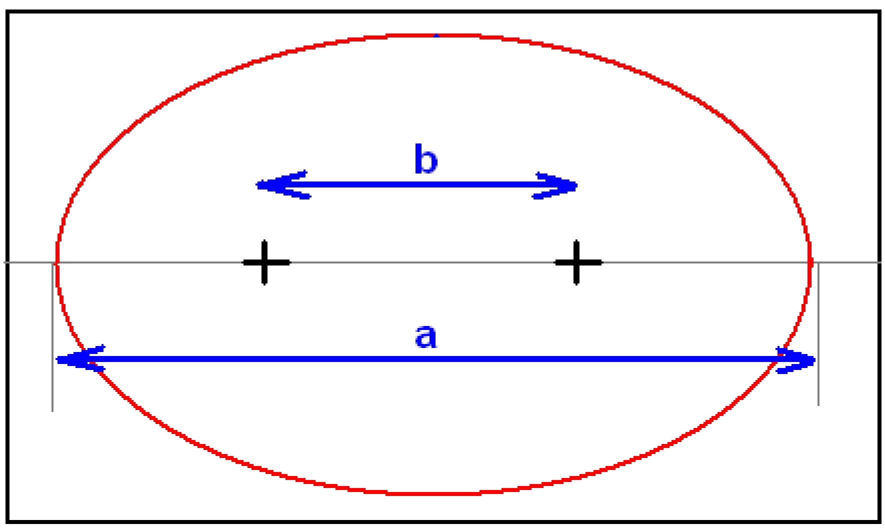
5. Your partner holds a pencil over each focus point. The loop of string guides a pencil to trace the ellipse as shown below. It is recommended that you trace the loop with your finger first, to make sure that the ellipse will fit entirely on the paper!



Use String to draw the Ellipse

6. Measure and record the size of the Major Axis (a) and the Inter-focal distance (b). Use this data to calculate the eccentricity of your ellipse. Eccentricity = b/a, and should vary between zero (a circle) and one (a line).

   - Eccentricity = ________________



Calculating Eccentricity and Circumference

7. A total of 5 ellipses need to be drawn on your paper. You may create the others in the following ways:

   - Remember: ***Your Star <u>cannot</u> move!***
   - Number each focal point and orbit so you know which ones go together!

- Move the other focal point in or out.
- Shorten the loop by at least 2 cm each time. It is OK if some orbits overlap.

8. Complete the data table shown below:

Trial	Semi-Major	Semi-Minor	Inter-Focal	Eccentricity
1:				
2:				
3:				
4:				
5:				

9. When calculating eccentricity for the table above, show ***one sample calculation only!***

10. Planet #3 is "***Novo Terra***" (New Earth), Choose a theme, and name your other four planets. The ancients named them after Greek Gods – you can pick rock bands, super heroes, famous scientists, etc. (***Be Nice!***) Use colored pencils or markers to draw in and label your 5 planets, each in its correct orbit about your star.

11. If the SMA (Semi-Major Axis) and orbital period of Novo Terra are 1 AU and 1 year respectively, use Kepler's 3rd law to calculate the orbital periods of your other four planets. ***Show one sample calculation only.*** Use your results to fill in the table below:

12. In your new solar system: 1 AU = 1.50 e^8 Km, and 1 year on Novo Terra = 467 days. Calculate the SMA distance of each planet in Km, and the length of each planets period in years and days. ***Show one sample calculation only.*** Use your results to fill in the table below:

Planet	Distance from sun (km)	Orbital Period (years)	Length of Year (days)
1:			
2:			
3: ***Novo Terra***			
4:			
5:			

Proving the Geocentric System False!

We have used the ping-pong ball models of the Earth, Sun, and Moon to explore the lunar phases and how they work, we will now expand our model set to include an ***inferior planet*** (Venus) and a ***superior planet*** (Mars) to demonstrate how Galileo was able to use his new astronomical telescope to prove that the Earth-centered model of the solar system was impossible.

In addition to teaching astronomy ideas and facts, we have an obligation to teach science both as a process and as a culture! One of the unique features of science is that when an old theory is proven false, it is abandoned. Astronomy offers us a powerful window into this process when we study the old ***Geocentric model*** of the solar system, and then transition to teaching the modern ***Heliocentric model.*** This activity helps students see how the old Earth-centered model was brought into question, and why we eventually abandoned it in favor of the Sun-centered model. There was nothing emotional or political about the final decision – it was based upon data!

You should already have a start to your solar system model with the Sun, Earth, and Moon made from ping-pong balls. Note that except for the Sun, each ping-pong model is painted half black to distinguish the lighted or 'day time' side of the planet from the unlighted or 'night time' side. Models do not have to be photographically accurate – on the contrary, since all solar systems in the Universe function in much the same way, students may be creative in making up their own planets if they wish!

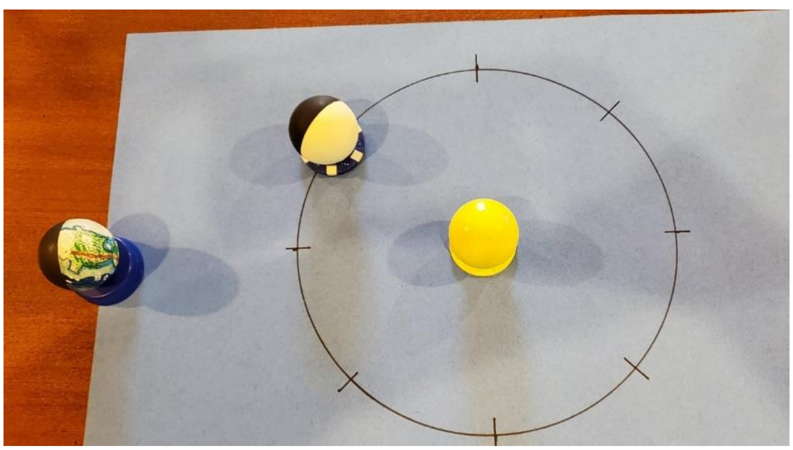
We will make a model of Venus – just a plain ping-pong ball, half black, half white. Venus is 100% cloud covered and shows no detail through the eyepiece anyway! Venus is referred to as an ***inferior planet*** because it lies inside the Earth's orbit (it is closer to the Sun that we are!) Our model of a ***superior planet*** (one that lies outside Earth's orbit) can be Mars, Jupiter, Saturn, etc. Your models should look something like this:

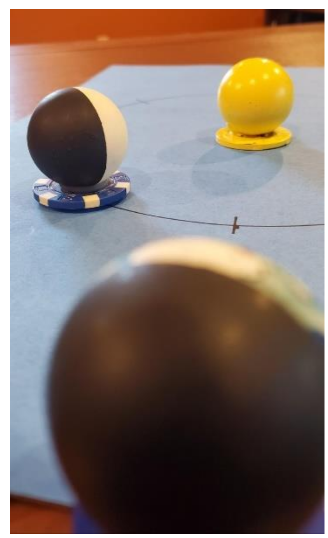
When you set up the model in a heliocentric configuration (See below), leave Earth in one position as shown, and move Venus around in its orbit, being sure to keep the lighted side facing the Sun at all times.

Put your eye or camera down near the Earth and look toward Venus. You will notice that Venus shows phases much like the Moon does. You would not be able to see either the New or Full phase for Venus. In both cases, the disk of Venus is lost in the glare of the Sun. You will also note that the Crescent phase of Venus occurs when the planet is closest to Earth – the crescent phase is the brightest! The larger Gibbous phase occurs when Venus is farther away from Earth, the planet appears smaller and therefore is less bright. These observations from our model match what you can see of Venus in the night sky with a good 10x binocular or small telescope!

Now try using a superior planet like Mars or Jupiter in our model. Be sure to place your superior planet at least 3x farther from the Sun than Earth. If your model is large enough (use at least a 1-meter circle for the superior planet with a 20 cm circle for Earth.) You will see that your superior planet doesn't show noticeable phases! Looking from Earth, the superior planet is too far away to show phases. This is what Galileo saw with his telescope looking at Venus and Jupiter in the early 1600's.

Now try to set up the model in a ***geocentric configuration*** with the Earth in the center and the Sun orbiting around our planet. Inferior planets were thought to be closer to Earth than the Sun and superior planets farther out. Remember to keep the lighted sides of the planets facing the Sun at all time. Set this system up how you will, ***you cannot make Venus show phases as it does in the night sky.***





It was this data, gathered with the newly invented technology of the astronomical telescope, that helped Galileo prove that the old Geocentric system was false. The evidence also strongly suggested that the Heliocentric system was probably true. It took more than a century of observations, along with the mathematical work on planetary orbits by Kepler and the work on gravitation and planetary orbits by Newton to cement the case for the new system.

If you have access to a small telescope, take the time to observe Venus weekly – you will see the planet change phases exactly as Galileo saw, and as the heliocentric model predicts!